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RESEARCH MEMORANDUM

FLIGHT INVESTIGATION AT HIGH-SUBSONIC, TRANSONIC,
AND SUPERSONIC SPEEDS TO DETERMINE ZERO-LIFT DRAG OF
BODIES OF REVOLUTION HAVING FINENESS RATIO OF 6.04
AND VARYING POSITIONS OF MAXIMUM DIAMETER

By

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

FLIGHT INVESTIGATION AT HIGH-SUBSONIC, TRANSONIC,
AND SUPERSONIC SPEEDS TO DETERMINE ZERO-LIFT DRAG OF
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By Ellis R. Katz

SUMMARY

Flight investigation of rocket-powered models was performed at high-subsonic, transonic, and supersonic speeds to determine the zero-lift drag of fin-stabilized bodies of revolution differing only in position of maximum diameter. The parabolic bodies were of 6.04 fineness ratio and had cut-off sterns with equal base area for all models. Pressure and drag data are reported at maximum diameter stations of 20, 40, and 60 percent of the body length.

At supersonic speeds the 60-percent station resulted in the least drag, and theoretical estimations at $M = 1.4$ indicated that the 60-percent position may be nearly optimum. At transonic speeds, equal drag resulted at the 40-percent and 60-percent stations and at subsonic speeds the position of maximum diameter had no effect.

INTRODUCTION

Practical flight at transonic and supersonic speeds has dictated the tendency toward large wing loadings for aircraft configurations. In addition, the use of thinner and stronger wings has resulted in accommodating greater fuel and fixed-equipment loads within the fuselage of the aircraft. The sum of the above two effects has been to increase considerably the size of the fuselage of the high-speed aircraft relative to the size of the wing. Thus, it is clear that the fuselage drag of supersonic aircraft, which is of the order of 30 percent of the

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total drag for present transonic configurations, is a major factor to be reckoned with in the quest for higher speeds. In order to investigate and clarify the phenomena of the fuselage drag rise associated with transonic and supersonic speeds, the NACA is conducting a series of flight investigations on bodies of revolution differing in fineness ratio and position of maximum diameter. The tests are conducted by means of rocket-propelled models at the Pilotless Aircraft Research Station, Wallops Island, Va. The preliminary investigation is presented in this paper and compares experimental and theoretical drag results for fin-stabilized bodies of 6.04 fineness ratio having maximum-diameter stations at 20, 40, and 60 percent of the body length.

The Mach number range of 0.6 to 1.85 corresponds to a Reynolds number range of 11×10^6 to 52×10^6 based on body length.

MODELS AND TESTS

The general arrangement of the test vehicles is shown in figure 1 and a photograph of the test configurations is shown as figure 2. The profiles of all the wooden bodies are described by parabolic arcs generated at the positions of maximum diameter. The equations describing the profiles of the bodies are given in figure 3. In all cases the frontal area (0.307 sq ft), base area (0.0586 sq ft), and length (3.77 ft) remain constant.

All models were stabilized by three 45° sweptback fins of 1.69 square feet total exposed area. The dural fins were of 0.0278 thickness ratio in the streamwise direction and so located that the trailing edge of the fins always intersected the body at 9.47 percent of the body length forward of the model base.

A two-stage propulsion system was employed utilizing a shortened 3.25-inch-diameter Mk.7 aircraft rocket motor as the sustainer unit and a 5-inch HVAR motor for the booster unit. The booster unit was stabilized by four fins and was attached to the sustainer motor by means of a nozzle plug adapter.

Data were obtained by the standard drag technique as used in reference 1. The technique utilizes a CW Doppler velocimeter, located at the launching site, for the purposes of measuring the deceleration of the model due to gravity and drag. The data are measured throughout the first 10 or 12 seconds of coasting flight (after burnout of the sustainer rocket motor) during which the flight path is virtually a straight line from the point of launching. Atmospheric conditions are recorded by means of radiosonde observations. A more complete

discussion of the method and of the accuracy of results obtained by use of this technique is found in reference 1. Two models were flown for each configuration investigated; however, one model (10b) failed to give satisfactory results and the data were omitted from the present paper.

RESULTS AND DISCUSSION

In figure 4 are shown the curves of drag coefficient, based on frontal area, against Mach number for the three tested configurations. The small degree of scatter in the data for identical models of a configuration is an indication of the reliability that may be placed upon the results. The variation of drag coefficient with Mach number may be considered through three ranges of velocity corresponding to the flow field around the body: the subsonic range which is terminated at the beginning of the rise of drag coefficient, the transonic range over which the drag coefficient rise is marked, and the supersonic range which begins at the end of the rise of drag coefficient. The Mach numbers which mark the transition between the speed ranges for the experimental curves are only approximate inasmuch as there are not sharp demarcations between types of flows.

The following table lists the approximate experimental transition Mach numbers for each of the body shapes investigated herein and also compares the transonic-supersonic transition with the shock-wave attachment Mach numbers for cones as given by some experimental results (reference 2) and by theoretical results from reference 3.

Position of maximum diameter K (percent)	Transition Mach number			
	Subsonic- transonic	Transonic-supersonic		
		Experiment (fig. 4)	Experiment (reference 2)	Theory (reference 3)
20	0.8	1.5	1.68	1.96
40	.92	1.2	1.20	1.28
60	.94	1.1	1.09	1.15

From figure 4 the 60-percent station appears to be the best as regards zero-lift drag through the Mach number range of these tests. Below $M = 0.8$ the position of maximum diameter had no effect.

For most of the transonic range ($0.82 < M < 1.02$), the 60-percent and 40-percent stations had significantly less drag than resulted from the 20-percent station of maximum diameter. Above $M = 1.10$ the 60-percent station resulted in approximately 15 percent less drag than did the 40-percent station and approximately 50 percent less drag than did the 20-percent station of maximum diameter. The foregoing discussion holds roughly true regardless of whether drag coefficient C_D is based on frontal area, wetted skin area, or $(vol)^{2/3}$.

By means of the method of Von Karman and Moore (reference 4), the pressure distribution was calculated at $M = 1.40$ for the configuration tested and, in addition, for an 80-percent position of maximum diameter D_{max} . These distributions are shown in figure 5. The calculations were made for only one supersonic Mach number in consideration of Laitone's work (reference 5) in which the method was concluded to be most accurate near $M = \sqrt{2}$. Although the method cannot be rigidly applied to the 20-percent maximum-diameter position (due to the questionable nature of the flow at $M = 1.4$), pressure distribution of the flow is included for the purpose of indicating the type of variation that might be expected for extreme forward positions of maximum diameter. As will be seen subsequently, inclusion of pressure distribution is further justified in view of its favorable agreement with experiment. The theoretical distributions are shown to be basically of two distinct types of variations depending upon the position of D_{max} relative to the position of symmetry. The position of symmetry is that station of D_{max} for which the nose and stern of the body are of equal curvature. For the test bodies of this paper, the 57.1-percent station is the relative position of symmetry. From figure 5, where the maximum diameter is well forward of the symmetry position, the characteristic variation is one of a strong compression at the nose followed by a rapid expansion to peak suction at the maximum diameter and then a gradual recompression to the stern. Where the maximum diameter is well behind the symmetry position, the characteristic variation is one of a relatively weak compression at the nose followed by a gradual expansion to the maximum diameter, and then by an extremely rapid expansion to a very large peak suction on the boattail. Since the method of pressure distributions is, however, based upon the assumption of small disturbances, it is doubtful whether peak suction of the order indicated in figure 5(d) would be correct to within the limits of the theory.

The variation of total drag with position of D_{max} has been calculated at $M = 1.40$ and is compared with the experimental variation in figure 6. The experimental variation was based on three test points and was, in part, guided by the calculated variation. The general agreement between calculated variation and the test points

appears to be reasonably good. The pressure drag coefficient has been computed from the distributions shown in figure 5. The friction drag coefficient was assumed to be 0.0027 based on wetted surface area throughout and varies only with the wetted area of the bodies considered. The base drag has been estimated from an unpublished summary of base pressure data and is assumed to be independent of body shape. The drag of the fins has been calculated from reference 6 using the approximate flow conditions at the leading edges of the fins and assuming a turbulent boundary layer across the fins. All of the aforementioned contributions result in greater total drag coefficients over the range tested than did the experimental results. The absolute discrepancy between the experimental and calculated values is much greater for the rearward positions of D_{max} .

No attempt has been made to allow for the interference effects between body and fin. However, a preliminary analysis indicated that, for rearward positions of maximum diameter, there exists a favorable effect of the fins on the body and a small unfavorable effect of the body on the fins. These effects have been concluded from a simple superimposing of the fin pressures on the body surface and the body pressures on the fin surface. In addition, the actual viscous effects would probably tend to decrease the calculated drag most for the bodies with rearward positions of D_{max} .

The correlation of the experimental data with the calculated variation of drag indicates that at $M = 1.40$ a location of the maximum diameter at the 60-percent station may be near the optimum position for least drag. Further tests to locate more precisely the position of maximum diameter for minimum drag appear warranted.

CONCLUSIONS

Flight tests were performed to determine the zero-lift drag of fin-stabilized bodies of revolution differing only in position of maximum diameter and having a fineness ratio of 6.04. Within the limits of the tests the following effects were noted:

1. At supersonic speeds, the 60-percent position was the most favorable location tested. Theoretical estimations at $M = 1.4$ indicated that the 60-percent station may be near the optimum position for least drag. Further tests to corroborate the theory appear warranted.

2. At transonic speeds, the 40-percent and 60-percent positions proved to be equally favorable locations of maximum diameter.

3. At subsonic speeds, the position of maximum diameter had no effect.

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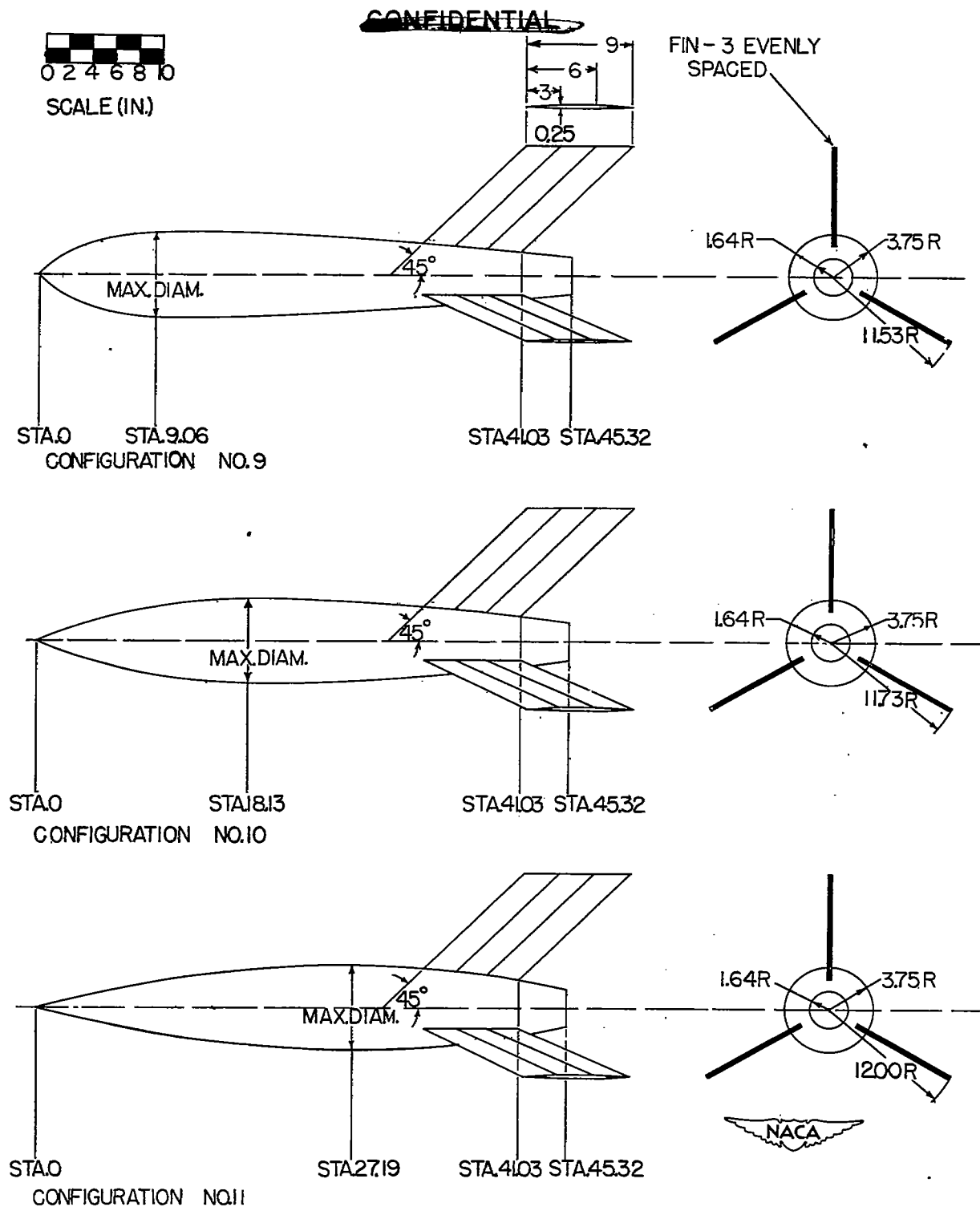


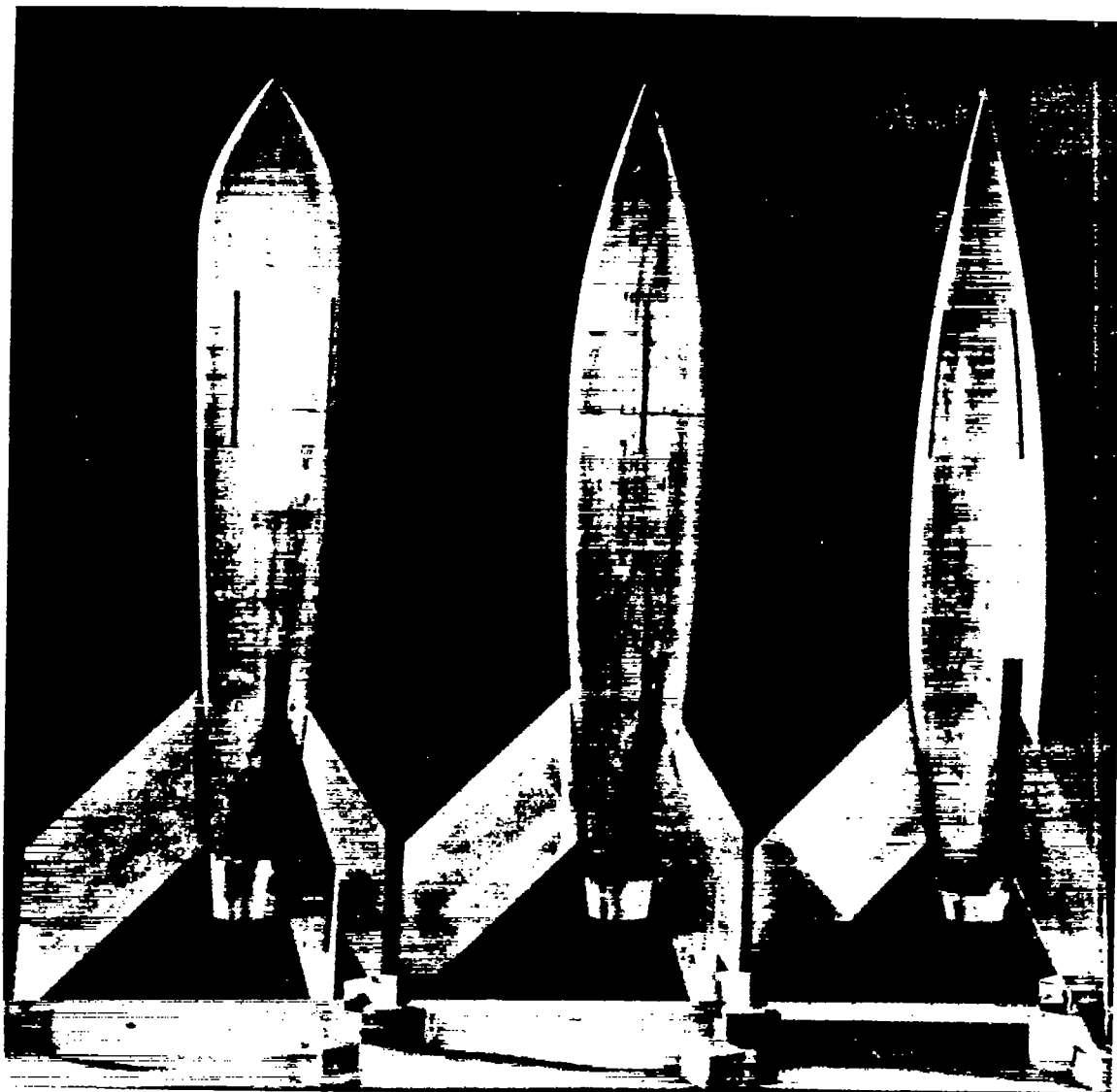
Figure 1.- General view of test configurations. Total exposed fin area = 243 square inches.

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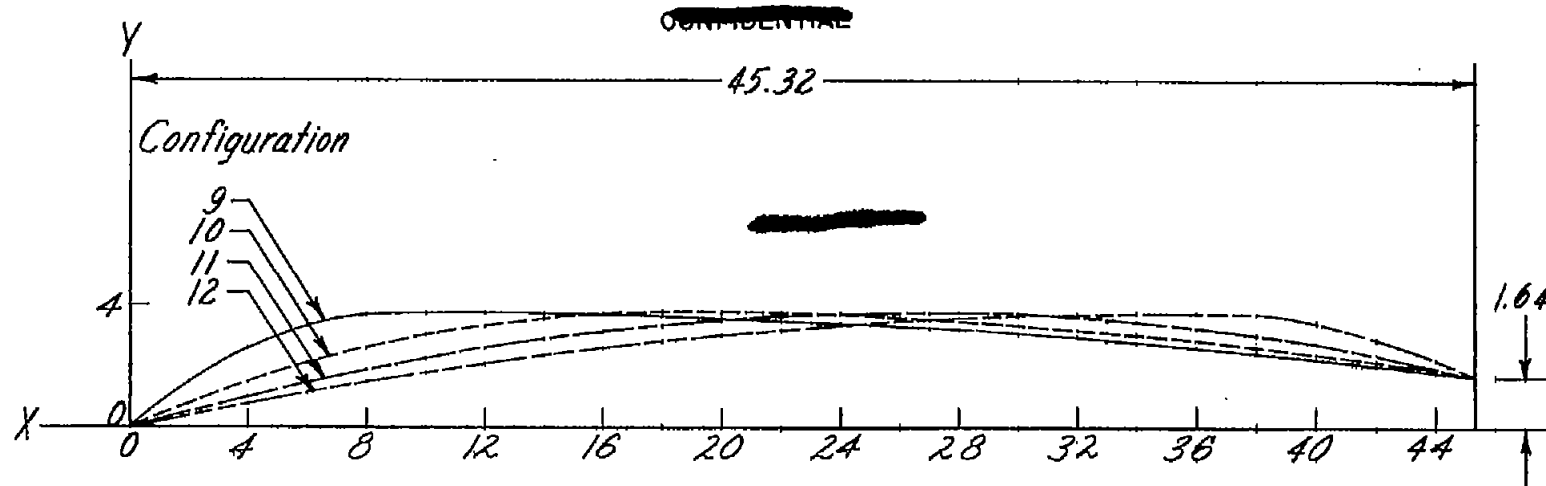
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Figure 2.- Test configurations having maximum diameters located at 20, 40, and 60 percent of body length from nose.

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General body-profile equations

$$\begin{cases} Y_1 = 3.75 - a(KL - X)^2 & [\text{from } X = 0 \text{ to } X = KL] \\ Y_2 = 3.75 - b(X - KL)^2 & [\text{from } X = KL \text{ to } X = L = 45.32] \end{cases}$$

Configuration	K	$a \times 10^3$	$b \times 10^3$
9	.2	45.64	1.61
10	.4	11.41	2.85
11	.6	5.07	6.42
12	.8	2.85	25.68



Figure 3.- Profiles and general equations for test configurations. Configuration 12 is shown as reference ~~for~~ theoretical calculations.

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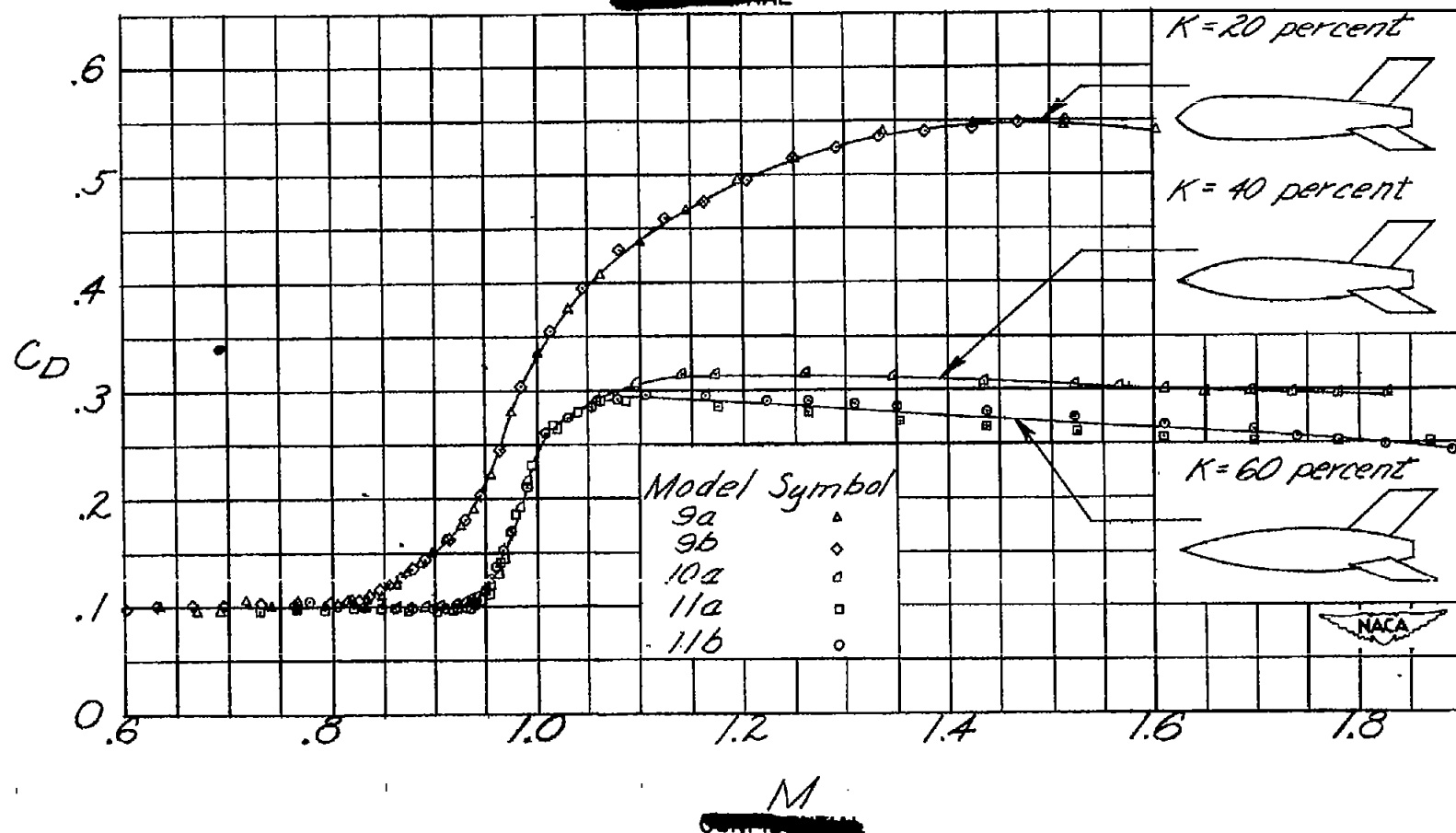
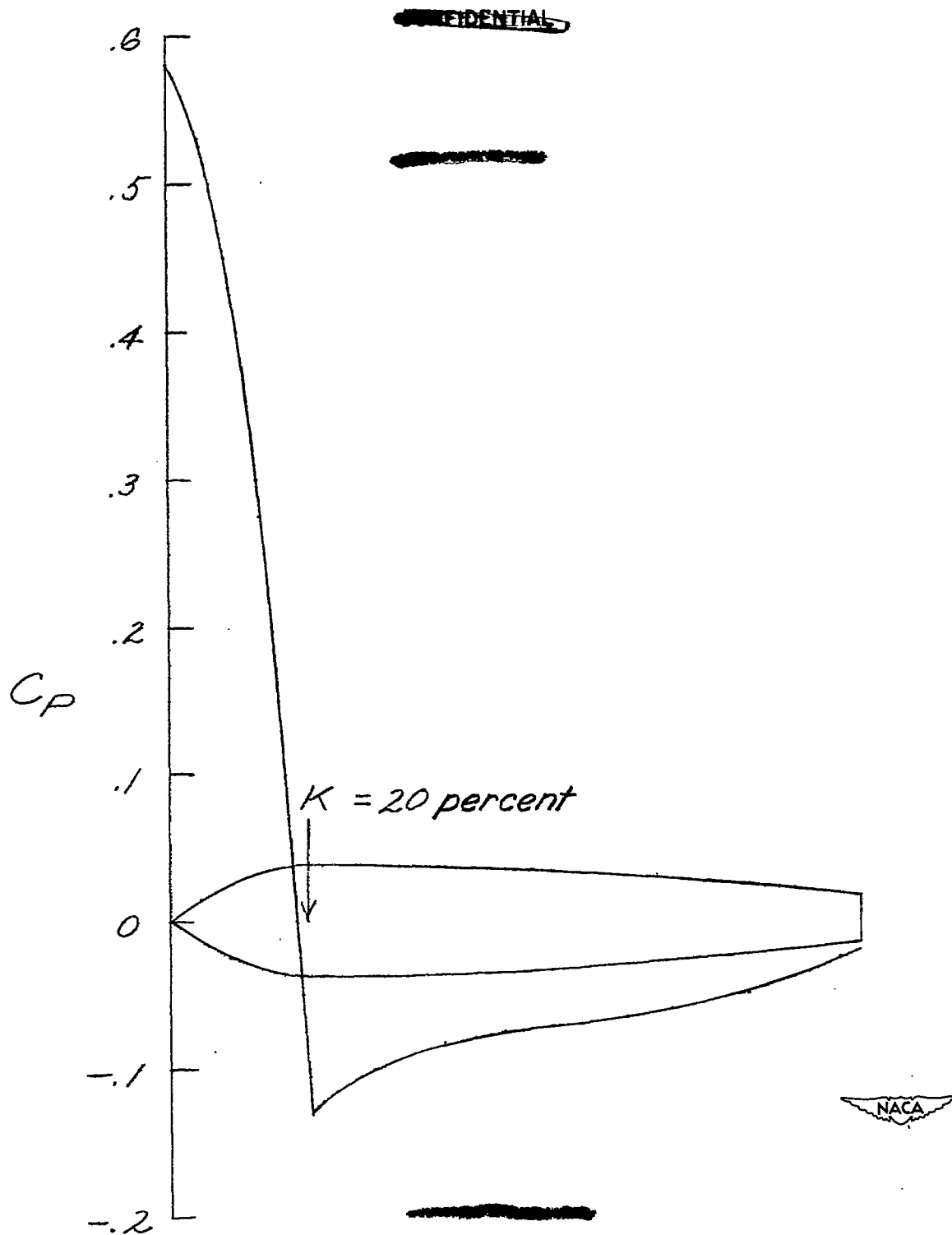


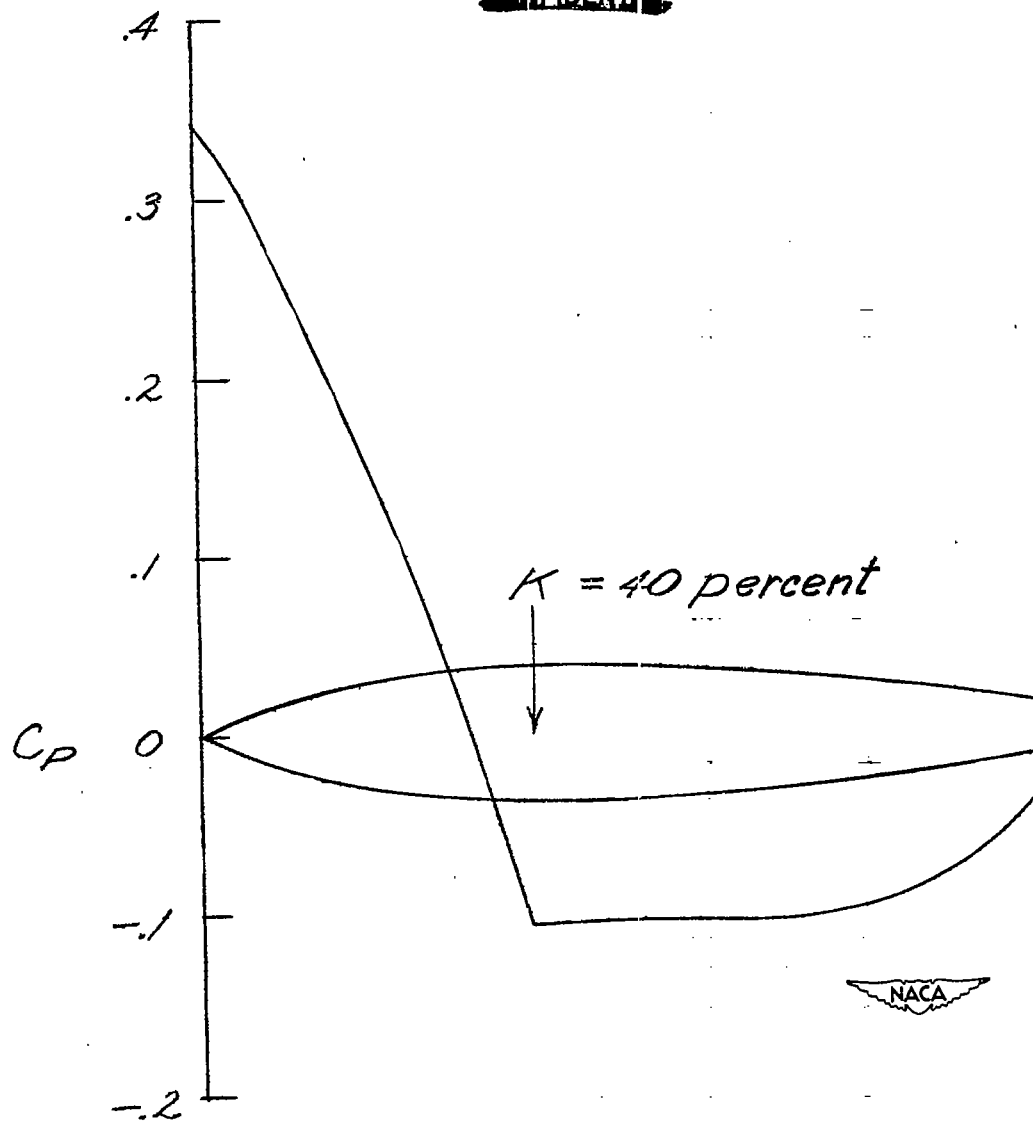
Figure 4.- Drag coefficient C_D plotted against Mach number M for three fin-stabilized bodies of revolution having various positions of maximum diameter K , percent of body length.



(a) Maximum diameter at 20-percent station.

Figure 5.- Theoretical pressure distribution at zero lift and $M = 1.40$.

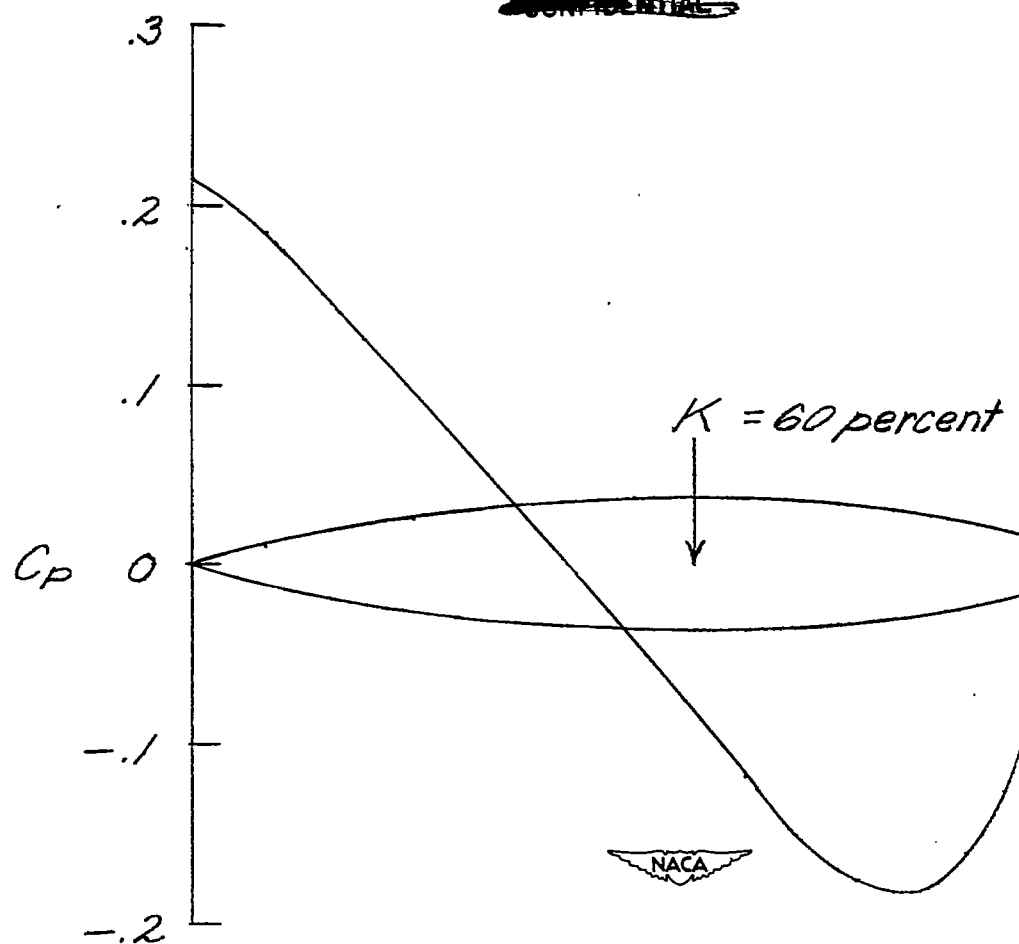
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(b) Maximum diameter at 40-percent station.

Figure 5.- Continued.

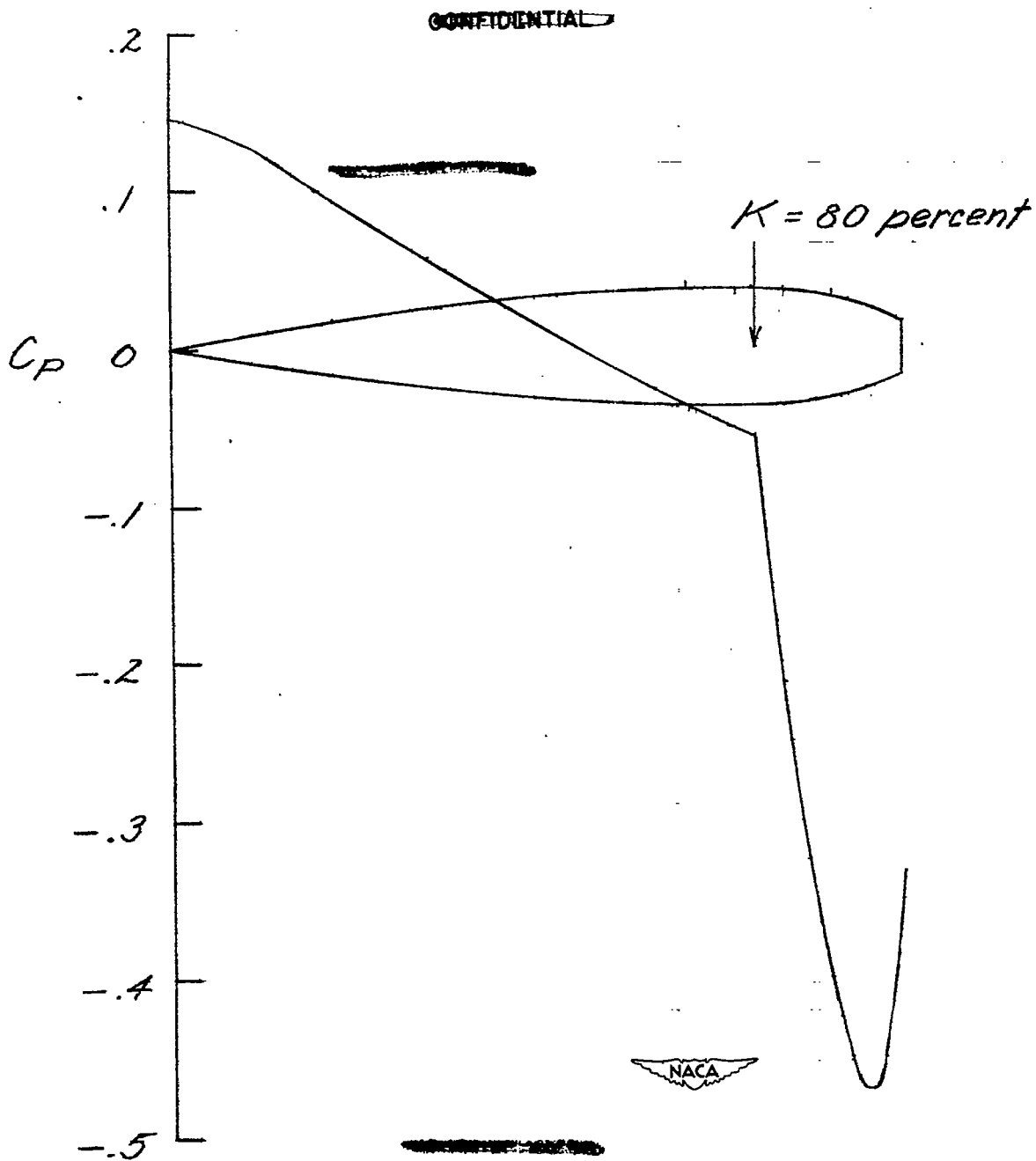
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(c) Maximum diameter at 60-percent station.

Figure 5.- Continued.

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(d) Maximum diameter at 80-percent station.

Figure 5.- Concluded.

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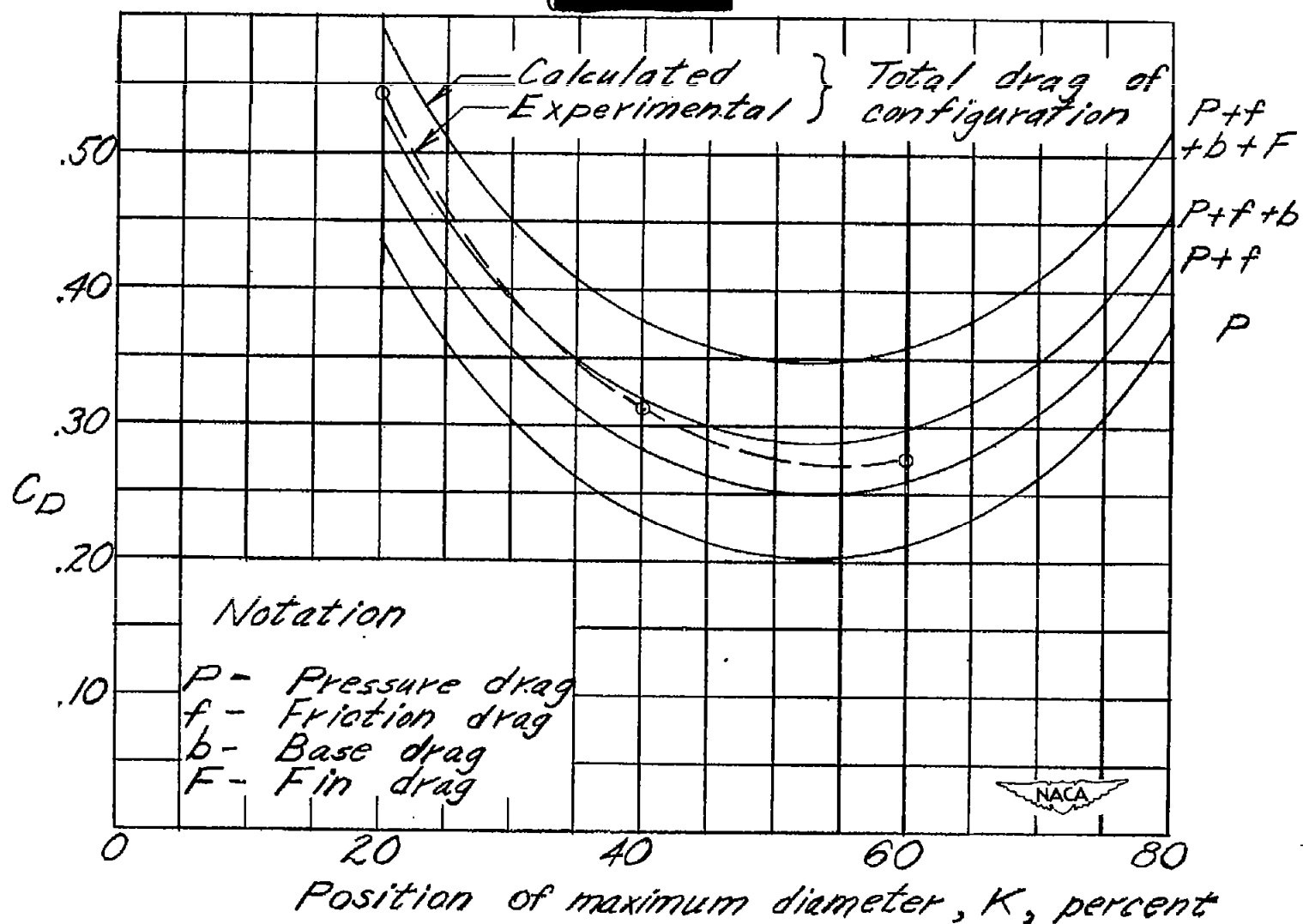


Figure 6.- Variation of drag coefficient C_D with position of maximum diameter. $M = 1.40$.